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Texture in the superconducting order parameter of $CeCoIn_5$; FFLO state as evidenced by ultrasound and NMR

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A myriad of fascinating properties have been proposed for unconventional superconductors in the presence of a strong magnetic field. Among the possible exotic superconducting (SC) phases, a spatially nonuniform SC state originating from the paramagnetism of conduction electrons has become a subject of particular interest after the pioneering work by Fulde and Ferrel and Larkin and Ovchinnikov (FFLO) in the mid-1960's. We present here ultrasound and NMR studies of the quasi-2D heavy-fermion superconductor $CeCoIn_5$ with extremely large Pauli paramagnetic susceptibility, which is believed to host a FFLO state. Ultrasound velocity measurements reveal an unusual structural transformation of the flux line lattice (FLL) in the vicinity of the upper critical field and with a magnetic field applied parallel to the *ab* plane. The transition field coincides with that at which heat capacity measurements reveal a second order phase transition. The lowering of the sound velocity at the transition is consistent with the collapse of the FLL tilt modulus and a crossover to quasi two-dimensional FLL pinning. In the vicinity of the upper critical field , the ^{115}In NMR spectrum also exhibits a dramatic change below $T^*(H)$ which well coincides with the position of reported anomalies in specific heat and ultrasound velocity. Below $T^*(H)$ a new resonance line appears at higher frequency, which can be attributed to the normal quasiparticle sheets formed in the SC regime. The NMR spectrum also indicate that the vortex core structure of $CeCoIn_5$ appears to be markedly different from that of ordinary superconductors. On the basis of these results, we were able to establish a clear evidence of the spatially inhomogeneous SC state at high field and low temperatures, precisely as expected in a FFLO state. In collaboration with T.Watanabe, Y.Kasahara, K.Izawa (Univ. of Tokyo), C.J. van der Beek(Ecole Polytechnique),K.Kakuyanagi, K.Kumagai (Hokkaido Univ.), M.Nohara, T.Hanaguri, H.Takagi,(Univ. of Tokyo) H.Shishido, R.Settai, and Y.Onuki(Osaka Univ.)